Indian J. Phys. **80** (2), 187-190 (2006)

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Multiple feedback third order active-*R* filter with varying tapping ratio *B*

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Received 12 May 2005, accepted 11 November 2005

Abstract A third order active-*R* filter using operational amplifiers (op-amp) and resistors, is designed with multiple feedback and feedforward input signal It is studied for different values of tapping ratio *B*. Center frequency F_0, circuit merit factor Q and the positive feedback resistor R which taps R_2 are kept constant at 60 kHz, 10 and 400 Ω, respectively. The circuit exhibits low pass, band pass and high pass response at corresponding output points The gain roll-off in low-pass response is unaffected by varying tapping ratio *B*. Band pass response for $B = 0.5$ shows better gain roll-off and is more symmetric in nature Bandwidth of the circuit decreases as *B* is increased In high pass response, overshoot increases with increase in *B* The gain [illegible] per octave in the transient part is about +14 dB for all values of *B* except 0.5, but the gain gets stabilized almost at 0 dB for $B = 0.5$.

Thus, it gives better performance for $B = 0.5$. It is easy to design, suitable for monolithic IC implementation and useful for high frequency operation It also gives better pass band gain

Keywords Center frequency, feedforward, filter, merit factor, multiple feedback, tapping ratio and third order

PACS Nos. 84.30 Vn, 07.50 Ek

1. Introduction

The proposed active-*R* circuit is designed and realized using op-amp μA741C. It is an internally compensated op-amp. An internally compensated op-amp is represented by 'integrator' model [1-3]. Various configurations of third order active-*R* filter have been proposed [4-7].

The third order active-*R* filter proposed in this paper, uses both positive and negative feedback *i.e.* multiple feedback and input signal fed forward [5, 8]. Change in the value of *B* varies the feedback. This filter has been studied for different values of *B*. The filter gives low pass, band pass and high pass response.

Circuit configuration

Figure 1 shows circuit diagram of the proposed third order active-*R* filter. It uses three op-amps (μA 741C) with identical gain-bandwidth-product (GB) and five resistors. The negative feedback is incorporated using resistors R_1, R_2 and R_3. Outputs of the three op-amps are fed back to the inverting terminal of the first op-amp. The resistor *R*, which in turn, is connected to non-inverting terminal of the second op-amp to constitute positive feedback, taps R_2. The tapping point of R_2 by *R* is changed *i.e.* *B* is varied. The input signal is fed forward to inverting input of the second op-amp.

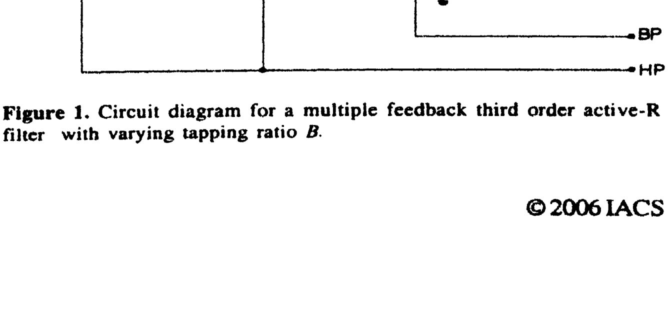

Figure 1. Circuit diagram for a multiple feedback third order active-R filter with varying tapping ratio *B*.

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3. Circuit analysis and design equations

Op-amp μA741C that is an internally compensated op-amp is represented by single pole model, also known as the 'integrator' model [2]. Its gain is complex and is given by $= 2\pi F$

$$A(S) = (A_0\omega_0)/(S+\omega_0)\,, \tag{1}$$

where

A_0 = open loop D. C. gain of the op-amp.,

ω_0 = open loop-3 dB bandwidth of the op-amp = $2\pi F_0$,

$A_0\omega_0$ = GB = gain-bandwidth-product of the op-amp.

For $S >> \omega_0$

$$A(S) = (A_0\omega_0)/S = GB/S\,. \tag{2}$$

Transfer functions of the proposed third order active-R filter: for low pass, $T_{LP}(S)$; for band pass, $T_{BP}(S)$ and for high pass, $T_{HP}(S)$ is given below.

$$T_{LP}(S) = -(1/R_4)GB_3\,GB_2\,GB_1\big/\left(X_1S^3 + X_2S^2 + X_3S + X_4\right), \tag{3}$$

$$T_{BP}(S) = -(1/R_4)GB_2\,GB_1\;S\big/\left(X_1S^3 + X_2S^2 + X_3S + X_4\right), \tag{4}$$

$$T_{HP}(S) = (1/R_4)\,S3\big/\left(X_1S^3 + X_2S^2 + X_3S + X_4\right), \tag{5}$$

where

$$X_1 = (1/R_1) + (1/(BR_2)) + (1/R_3) + (1/R_4) - ((1-B)\,RM)/B\,,$$

$$X_2 = GB_2(RM) + GB_1\left((1/R_1) + (1-B)\,R_2M\right),$$

$$X_3 = (GB_3GB_2/R_3) + GB_2GB_1(RM)\,,$$

$$X_4 = GB_3\,GB_2\,GB_1\,/\,R_3\,,$$

$$M = 1\big/\left(RR_2 + B(1-B)R_2^2\right).$$

The circuit has been designed using coefficient-matching technique with general third order filter transfer function [3].

$$T(S) = \left[H_3\,S^3 + H_2\,S^2 + H_1\,S + H_4\right]\big/$$
$$\left[S^3 + \omega_0((1/Q)+1)S^2 + \omega_0^2((1/Q)+1)S + \omega_0^3\right]. \tag{6}$$

Design equations are obtained by comparing eqs. (3), (4) and (5) with (6).

$$X_1 = (1/R_1) + (1/(BR_2)) + (1/R_3) + (1/R_4) - ((1-B)\,RM)/B = 1\,. \tag{7}$$

$$X_2 = GB_2(RM) + GB_1\left((1/R_1) + (1-B)\,R_2M\right)$$
$$= \omega_0((1/Q+1)\,, \tag{8}$$

$$X_3 = (GB_3GB_2/R_3) + GB_2GB_1(RM) = \omega_0^2((1/Q+1)\,, \tag{9}$$

$$X_4 = GB_3GB_2GB_1/R_3 = \omega_0^3\,. \tag{10}$$

Eq. (7) to (10) are used to determine values of R_1, R_2, R_3 and R_4 for different values of Q.

Table 1. Resistance values.

B	Designed values (Ω) Used values (Ω)			
	R_1	R_2	BR_2	$(1-B)R_2$
0.12	55.70 k	4.17 k	500	3.67k
	55.70 k	4.17 k	500	3.67k
0.3	2.40 k	3.25 k	974	2.27k
	2.40 k	3.25 k	972	2.28k
0.5	1.58 k	3.03 k	1.515k	1.515k
	1.58 k	3.02 k	1.51k	1.51k
0.7	1.27 k	3.25 k	2.27k	974
	1.27 k	3.25 k	2.28k	970
0.9	1.06 k	4.41 k	3.97k	441
	1.06 k	4.41 k	3.97k	440

Values of R_1, R_2, R_3 and R_4 for some values of B with F_0 = 60 kHz, Q = 10 and R = 400 Ω are given in the Table 1. For practical implementation, the values of all the resistances are impedance scaled by 100.

The resistances R_3 and R_4 remain unaltered for changes in B. The designed values are 81.30 k Ω and 113 Ω, respectively. The values used are 81.25 k Ω and 113 Ω, respectively.

4. Experimental

The circuit performance is studied for different values of B with F_0 = 60 kHz, Q = 10 and R = 400 Ω. The general operating frequency range of this filter circuit is 10 Hz to 1 MHz, as the operating frequency range of μA 741C op-amp is 10 Hz to 1.2 MHz [9]. The value of GB (= GB_1 = GB_2 = GB_3) is 2π (5.6) 10^5 rad / sec.

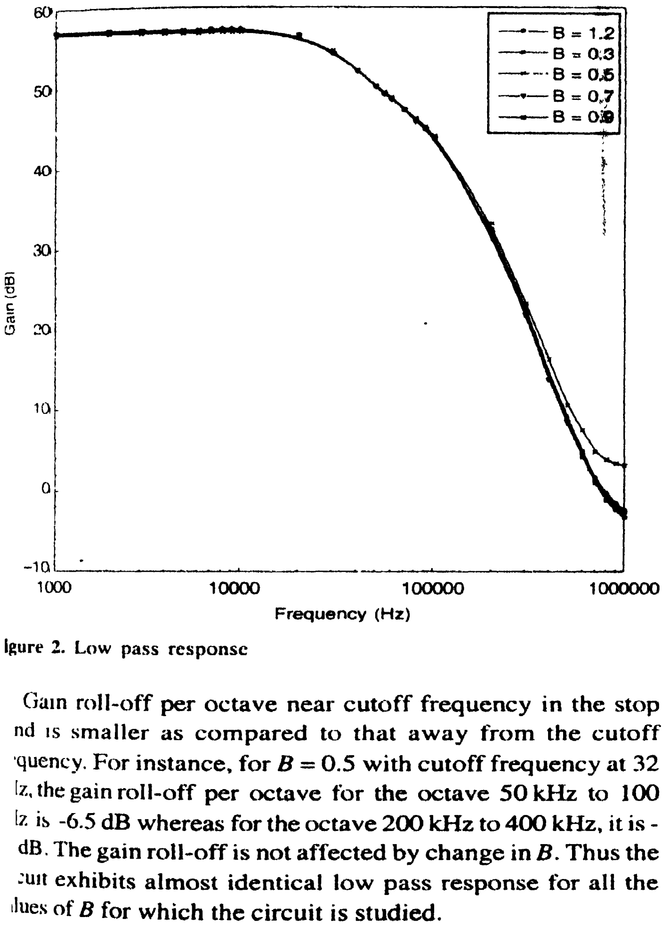
This circuit is also studied for different values of F_0, Q and R.

5. Results and discussion

From experimental study of this filter, following observations are noticed for low pass, band pass and high pass at the corresponding output terminals. Response of the circuit is tudied for different values of B (0.12, 0.3, 0.5, 0.7 and 0.9.) For ealization of the circuit, the resistances must be positive. Hence, ie value of B has limit. In this case, the theoretical limit is .1154 ≤ B ≤ 0.9999.

A) Low pass response :

igure 2 shows the low pass response for different values of The cutoff frequency is found to shift. The shift is almost the ame for all values of B for which the circuit is studied.



lgure 2. Low pass response

Gain roll-off per octave near cutoff frequency in the stop nd is smaller as compared to that away from the cutoff quency. For instance, for B = 0.5 with cutoff frequency at 32 lz, the gain roll-off per octave for the octave 50 kHz to 100 lz is -6.5 dB whereas for the octave 200 kHz to 400 kHz, it is - dB. The gain roll-off is not affected by change in B. Thus the cuit exhibits almost identical low pass response for all the lues of B for which the circuit is studied.

B) Band pass response :

gure 3 shows band pass response of the filter circuit for fferent values of B. Shift in the center frequency is observed r all values of B. The shift is almost the same for all values of is decreased below and increased above 0.5.

Bandwidth of the circuit decreases as B is increased. In the ss band, distribution of frequencies is more symmetric for = 0.5 *i.e.* the curve for B = 0.5 is more symmetric. Maximum ss band gain increases as the value of B is increased.

Gain roll-off /octave in the leading part of the stop band is slightly larger for B = 0.5. The gain roll-off is almost the same (10dB/octave) for other values of B. Gain roll-off in the trailing

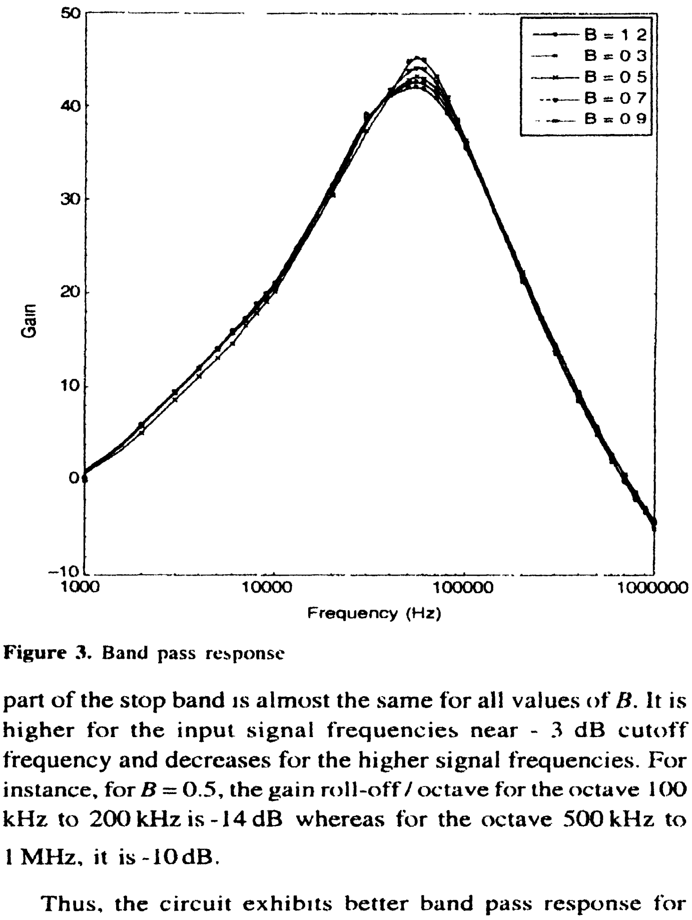


Figure 3. Band pass response

part of the stop band is almost the same for all values of B. It is higher for the input signal frequencies near - 3 dB cutoff frequency and decreases for the higher signal frequencies. For instance, for B = 0.5, the gain roll-off / octave for the octave 100 kHz to 200 kHz is -14 dB whereas for the octave 500 kHz to 1 MHz, it is -10 dB.

Thus, the circuit exhibits better band pass response for B = 0.5.

(C) High pass response :

High pass response of the filter for different values of B is shown in Figure 4. In transient part of the response, gain roll-off per octave is small (12.5 dB) for B = 0.5 and large for other values of B.

Overshoot occurs in the response. The frequency F_{os} at which overshoot occurs is the same (80 kHz) for B ≤ 0.5. F_{os} is also same for B > 5 but slightly less (70 kHz). Peak magnitude of the overshoot increases with increase in B. The gain gets stabilized almost at 0 dB for all values of B = 0.5 at about 300 kHz signal frequency and for other values of B, the gain gets stabilized almost at – 0.5dB at about 400 kHz signal frequency.

Thus, the high pass response of the circuit is better for B ≤ 0.5.

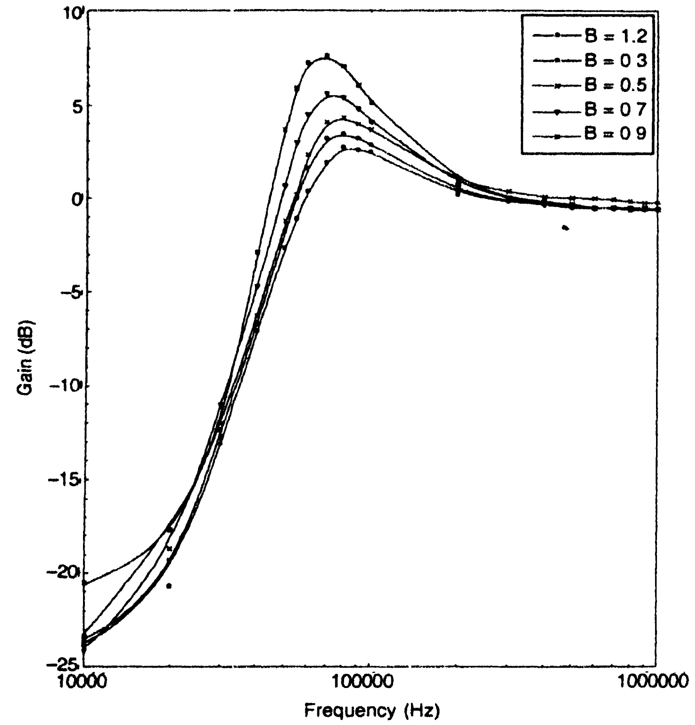


Figure 4. High pass response.

6. Conclusion

The circuit gives low pass, band pass and high pass response. In low pass response, the gain roll-off almost remains unaffected by varying tapping ratio B. It gives slightly better gain roll-off and more symmetric pass band in band pass response for B 0.5. Bandwidth of the circuit decreases as B is increased In hi pass response, overshoot increases with increase in B Ti gain roll-off per octave in the transient part is about +14 dB f all values of B except 0.5, but the gain gets stabilized almost at dB for $B = 0$.

Thus, it gives better performance for center tap ($B = 0$ It uses only three op-amps and five resistors.

Acknowledgments

Authors are thankful to the UGC, Western Regional Office, Pu (India) for providing financial assistance to Dr. G. N. Shinde fi Research project and FIP to P. D. Achole.

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